Low Frequency Marsquakes and Where to Find Them: Automated Event Back Azimuth Determination Using a Multi-Body Wave Polarisation Analysis Approach

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Image: G. Zenhäusern/ETH Zürich

NASA InSight mission on Mars

- Single seismic station recording since 2019
- Stationed in Elysium Planitia

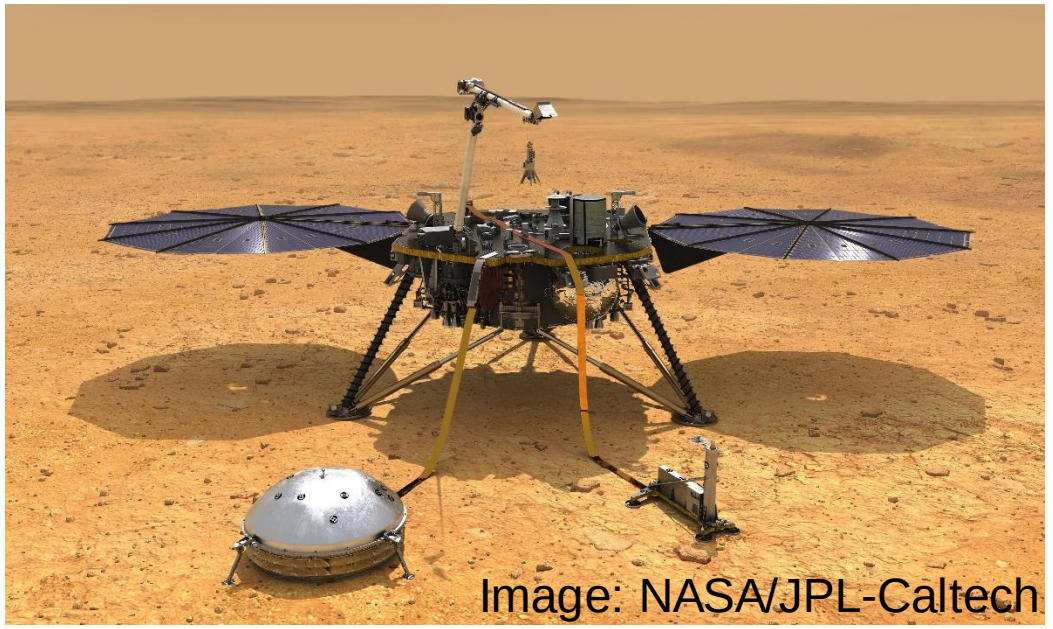


Image: NASA/JPL-Caltech

- Recorded over 1300 marsquakes to-date
  - High frequency family:
    - main energy at and above 2.4 Hz, highly scattered
    - origin mostly unclear
  - Low frequency family:
    - main energy < 2.4 Hz
    - ‘classical’ quakes
    - Location determined by distance and back azimuth (BAZ)
  - Mostly very low SNR (<10), often wind contaminated

Version 9 of the Marsquake Catalog:
- 69 low frequency events
- 6 have a location

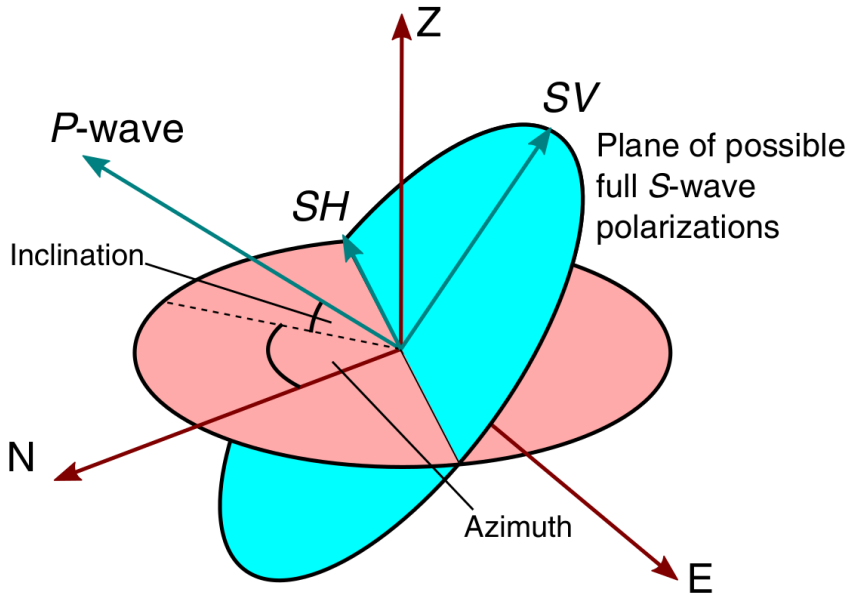
Most quakes lack a BAZ!

Where is Mars shaking?

Back azimuth estimation using polarisation analysis

Marsquake service (MQS) method:

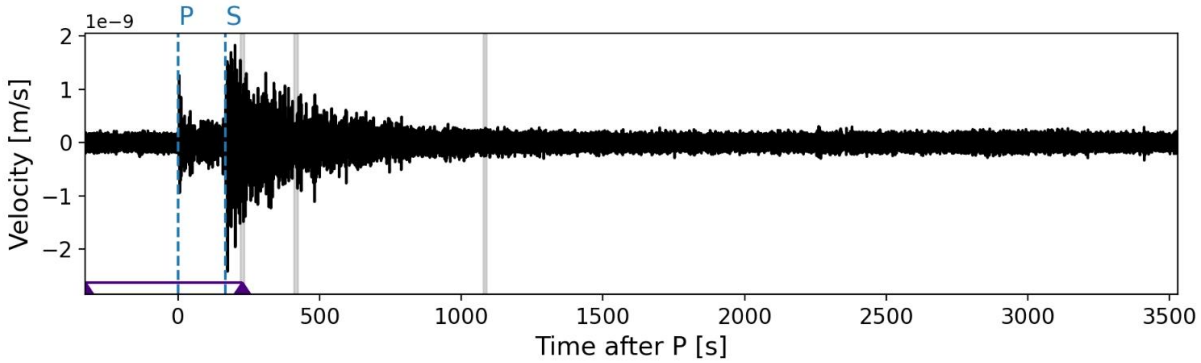
- Particle motion of short window of P-wave
  - Highly frequency dependent
  - Signal stability difficult to assess
  - Restricted to P-wave information



Eigenvector method:

- Derive Polarisation attributes from eigenanalysis of spectral matrix
  - Better frequency information
  - Information on inclination, ellipticity of the signal – helpful for noise discrimination
- Use information contained in P and S-wave: S-wave should be in plane perpendicular to P-vector

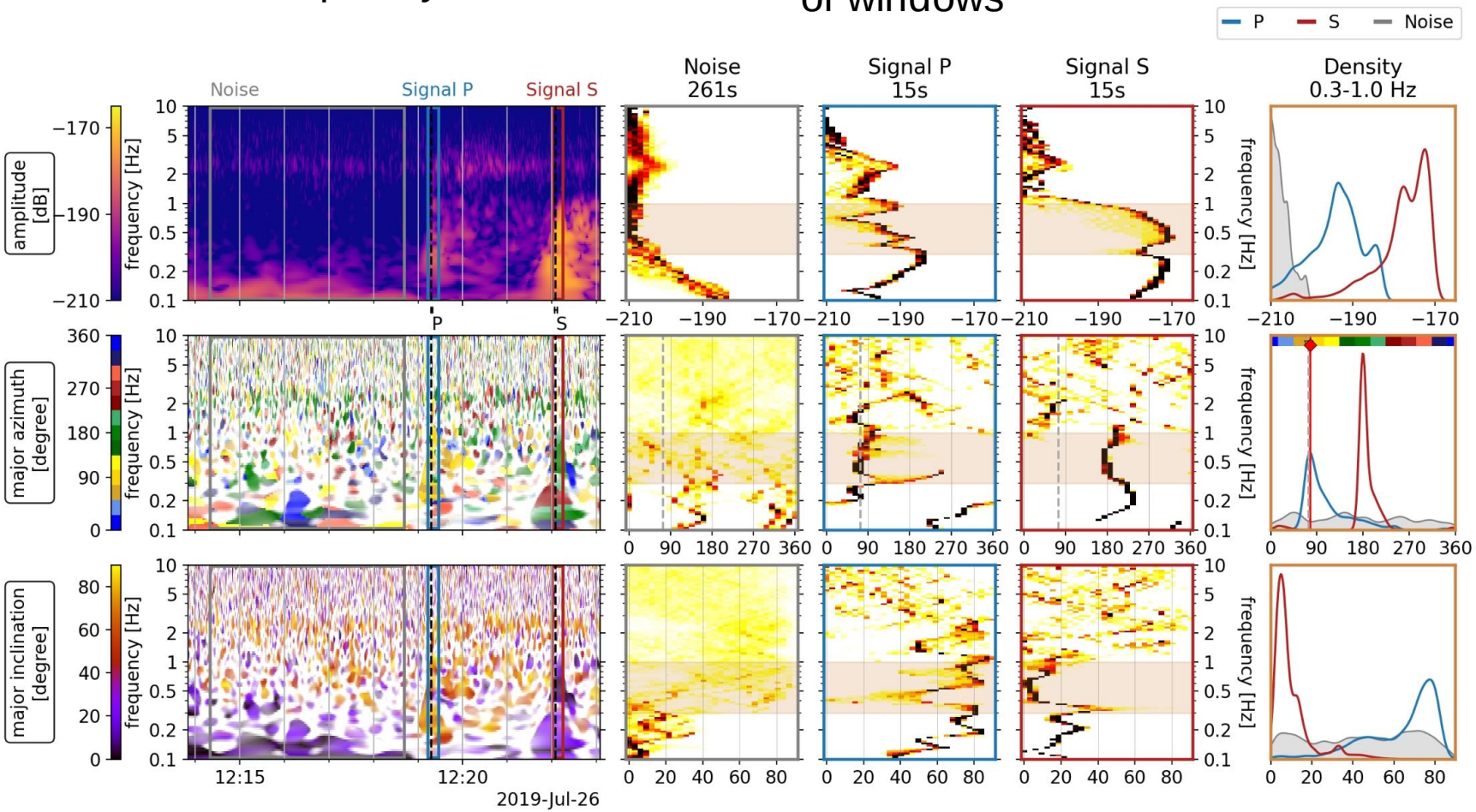
Example: Marsquake S0235b



Frequency - time

Histograms of windows

KDE of windows



Analyse 3 windows

- Noise
- 15s P-wave
- 15s S-wave

Estimate BAZ from KDE of

- Azimuth
- Inclination

KDE: Kernel density estimation

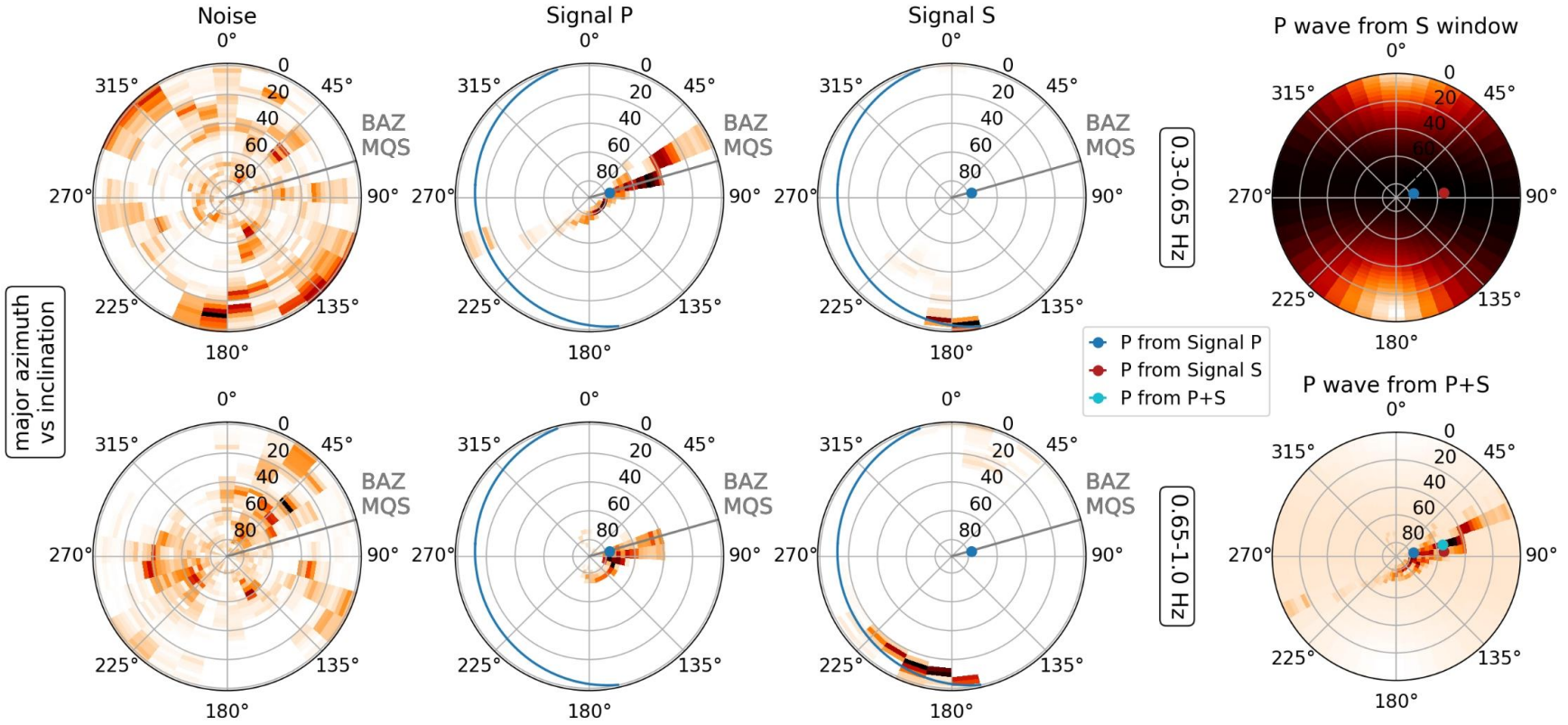
Example: Marsquake S0235b – azimuth vs. inclination

P-wave:

- Vertical
- In direction of BAZ

S-wave:

- Perpendicular to P
- SV/SH ratio depends on focal mechanism → unknown



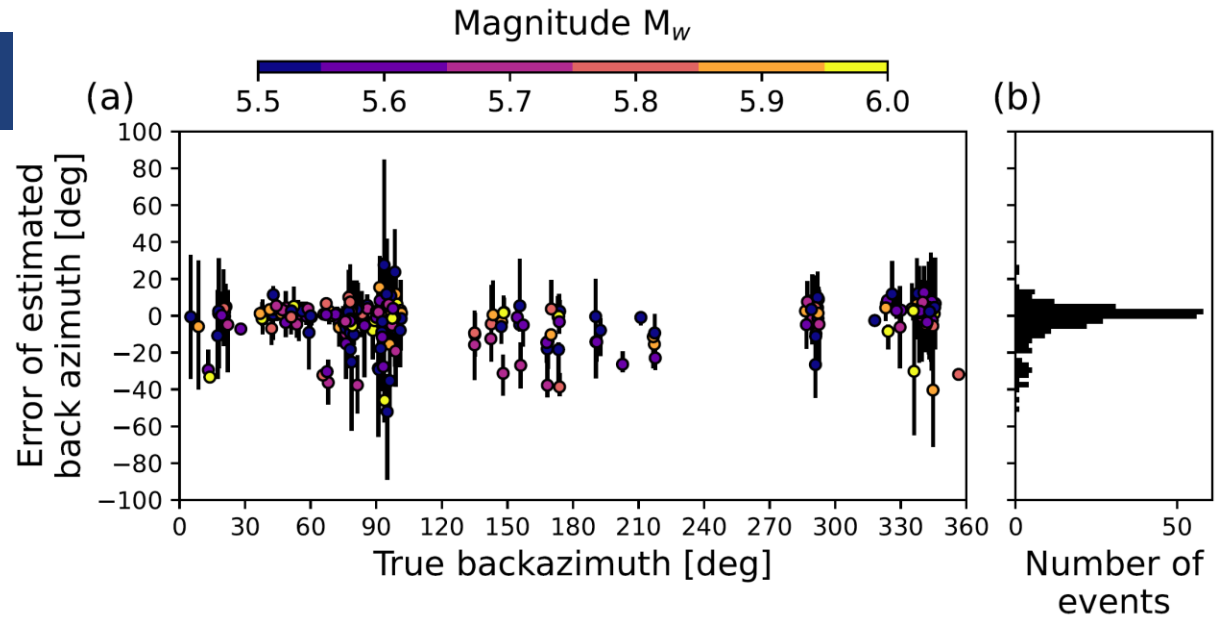
1. BAZ from P-wave
2. Fit with S-wave
3. BAZ from S-wave
4. Compare results (and compare to pre-event noise)

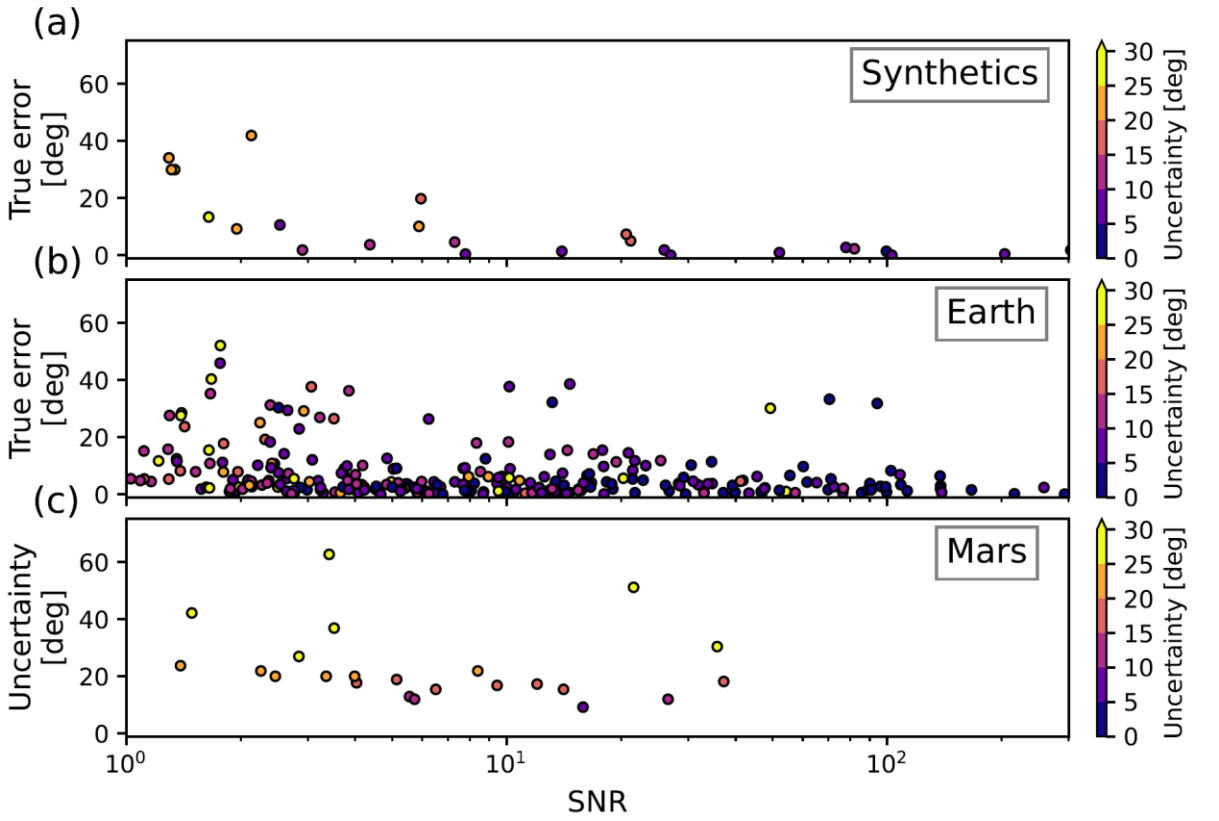
Earthquakes and synthetics

>250 Earthquakes:

- Recorded at Warramunga array (Australia)
- Error in estimated BAZ <10° for 213 events

Error in estimated BAZ smaller for larger Signal-to-Noise (SNR)





Results and summary

- We find the back azimuth is reliably estimated with this method, tested on synthetic marsquakes and a set of earthquakes

- We estimate back azimuths for 24 marsquakes, up from 8

- Most events are located close to the Cerberus Fossae graben system (black in (a); red in (b))